APPLICATION OF PROCESS MODELING TOOLS TO SHIP DESIGN

David A. Helgerson; CSC Advanced Marine Center
Seth Cooper; NAVSEA
Frank Waldman; LATTIX

May 2011
### Report Documentation Page

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

<table>
<thead>
<tr>
<th>1. REPORT DATE</th>
<th>MAY 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. REPORT TYPE</td>
<td></td>
</tr>
<tr>
<td>3. DATES COVERED</td>
<td>00-00-2011 to 00-00-2011</td>
</tr>
</tbody>
</table>

| 4. TITLE AND SUBTITLE | Application of Process Modeling Tools to Ship Design |

| 5a. CONTRACT NUMBER |         |
| 5b. GRANT NUMBER |         |
| 5c. PROGRAM ELEMENT NUMBER |         |
| 5d. PROJECT NUMBER |         |
| 5e. TASK NUMBER |         |
| 5f. WORK UNIT NUMBER |         |

| 6. AUTHOR(S) |         |

| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) | CSC Advanced Marine Center, 1201 M Street SE # 400, Washington, DC 20003-3721 |
| 8. PERFORMING ORGANIZATION REPORT NUMBER |         |

| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) |         |
| 10. SPONSOR/MONITOR’S ACRONYM(S) |         |
| 11. SPONSOR/MONITOR’S REPORT NUMBER(S) |         |

| 12. DISTRIBUTION/AVAILABILITY STATEMENT | Approved for public release; distribution unlimited |

| 13. SUPPLEMENTARY NOTES | Presented at the 23rd Systems and Software Technology Conference (SSTC), 16-19 May 2011, Salt Lake City, UT. |

| 14. ABSTRACT |         |

| 15. SUBJECT TERMS |         |

| 16. SECURITY CLASSIFICATION OF: |         |
| a. REPORT | unclassified |
| b. ABSTRACT | unclassified |
| c. THIS PAGE | unclassified |

| 17. LIMITATION OF ABSTRACT | Same as Report (SAR) |
| 18. NUMBER OF PAGES | 28 |
| 19a. NAME OF RESPONSIBLE PERSON |         |

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18
Summary, up front

• Navy warships are:
  – Complicated
  – Highly integrated
  – Multi-mission
  – Designed by the Naval Sea Systems Command (NAVSEA)

• Naval ship design involves:
  – Large design teams
  – Long design schedules
  – Complicated acquisition procedures

• We are applying commercial process modeling techniques for:
  – Better Management
  – Process Improvement
  – Tool Evaluation
  – Training
Initial Motivation

• We needed a method for prioritizing software development.
• How should scarce resources for software be spent?
• Where would the highest return on investment be achieved?

We expected that a Ship Design Process Model would show:
  • Where software was currently used;
  • Labor intensive activities;
  • Critical Paths; and
  • ROI.
Typical Navy Surface Combatant
DDG 51 Flight 1 Class Destroyer

Length = 505 ft
Beam = 59 ft.
Displacement = 8,230 Ltons
Speed = 30+ knots
Crew = 276

Armament: Missiles, Torpedoes, Guns, Helicopters

We modeled the design process for a conventional surface combatant because it was:
Sufficiently complex, but not as complex as an aircraft carrier;
And it fit our organizational priorities.

# Navy Ship Design and Acquisition Process

## DON Requirements

### OSD/Joint Level
1. JROC Approval
2. CD
3. JROC
4. MS.A
5. JROC
6. MS.B

### Navy/USMC Level
1. CBA
2. ICD Approval
3. Alternative Selection
4. CONOPS Approval
5. Final Selection
6. SSAC
7. SDD

### PEO/SYSCOM/OPNAV/HQMC Level
1. ROM Design, Technology Assessment, Analysis of Alternatives (AoA)s & Feasibility Studies
2. Preliminary Design (PD) & Contract Design (CD)
3. Detail Design & Construction (DD & C)

---

**Statement A:** Approved for Public Release; Distribution is unlimited.
An Integrated Model for the Entire Ship Design Process

- We built a process model that could show all phases
- Initial efforts focused on Preliminary Design
  - Large number of participants
  - Many inter-related activities
  - High return on investment for improvements
Interactions at all levels

- **Exchanges of information occur:**
  - Within Disciplines
  - Between Disciplines in the NAVSEA Organization
  - Between NAVSEA and NAVSEA Warfare Centers
  - With Contractors providing support at any level

- **Exchanges of information become more complex when organizations are under separate leadership.**

- **Dependencies between Activities = Implied Commitments**

- **Timeliness and Quality matter**

A process model defines commitments, enabling effective management.

“**They didn’t give me what I needed.**”

“**I didn’t get it in time.**”

“**I don’t know who is responsible.**”
Our Process Modeling Objective

• We set out to evaluate and prioritize new software development.
• We needed:
  – Consistent understanding of where tools were used
  – Means for determining ROI
• Developing a process model supported these objectives, and more . . .
• Our objectives expanded:

![Diagram of process model with categories: Design, Process Model, Project Planning, Process Improvement, Staff & Software Capability Analysis, Training]
Varied Understanding of Process

- We interviewed experts in specific technical areas.
- Some experts were not good at explaining their processes.
- If you cannot explain your process, how can you:
  - Discuss your role on the design team
  - Ensure you meet your commitments
  - Improve your process
  - Teach others about your process

We conducted semi-annual workshops to bring experts together.
Workshop Timeframe

Warrant Holder (Expert) Interviews
- 28-30 May 2008 Williamsburg, VA
- 21-23 October 2008 Cambridge, MD
- 31 March – 2 April 2009 Carderock, MD
- 1-4 December 2009 Carderock, MD
- 2-4 November 2010 Carderock, MD
- 7-8 April 2011 Dahlgren, VA

2008 DSM Conference
2009 DSM Conference
2010 DSM Conference
HM&E Process Development
Innovation Center Validation
Combat System Process Development
Application in Support of Ship Design

Calendar Years 2008 2009 2010 2011 2012

6 Workshops in 3 Years

Discussing use of model in support of funded ship design projects.

Goal: Build Process Modeling Practice Based on Successful Application.
### Design Structure Matrix Methods

- We used Design Structure Matrix methods to capture process definition.
- For info on DSM, see: [http://www.dsmweb.org/](http://www.dsmweb.org/)
- Workshop breakout sessions:
  - Experts brought together
  - Process activities identified; no need to worry about order
  - Dependencies identified
  - DSM put activities in order
  - Identifies highly interrelated clusters
  - Experts modified activities until satisfied
  - Deliverables and other details identified for each dependency

#### Table: Design Structure Matrix

<table>
<thead>
<tr>
<th>Step Description</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Review and Interpret Requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Provide Susceptibility System Inputs (EXTERNAL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Provide Recoverability System Inputs (EXTERNAL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluate Prior Phase (AoA) Designs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Define Vital Systems and Spaces</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Hit Distribution (EXTERNAL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Add Design Detail where Required</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conduct Trade-Offs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluate Shock</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluate Holing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluate Whipping</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perform Vulnerability Assessment (Modeling)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perform Damage Stability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prepare Cost Estimate Sheets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conduct Risk Assessment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generate Cost Estimates (EXTERNAL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capture Uncertainty in Assessments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Make Recommendations for Survivability Chks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Report Vulnerability Results/Conclusions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Reliability Growth Plan</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output Recoverability System Assessment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output Susceptability System Assessment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Different People – Different Preferences

• **We need to view process data in multiple formats.**
  – DSM
  – GANTT Charts
  – “Boxes and Arrows” (IDEF)
  – Tabulated Data

• **The data must be consistent in all formats.**

• **We would like easy export to other applications**
  – Excel® files
  – CSV files
  – XML
Different People – Different Preferences

Complete Sequential Flow Chart

Flow Chart by Geography

Gantt Chart

DSM
Multi-domain Views of Process

• **It is helpful to evaluate a project from multiple perspectives**
  – Process Order
  – Work Breakdown Structure
  – Organizational Responsibility
  – Geographic Location
  – Software Tools or Other Resource Dependency

• **The model being developed can produce output organized by domains of interest**

• **Examples:**
  – Division of Labor by Discipline
  – Critical Path
  – Organizational Distribution of Responsibility
  – Balance of effort by Worksites

• Is your project collocated at the desired level?
• Is there a participant on the Critical Path that is remotely located?
Complexity & Comprehension

• No need to model infinite detail
• We estimated we could comprehend about 1,000 objects.
• Our Preliminary Design Model is comprised of:
  – ~250 Activities
  – ~700 Dependencies
• In practice, this has worked out to be just about right.
• Keeping major blocks to this size is a good rule of thumb.
• Several blocks are modeled.
• Other conventions are also important:
  – Standard terminology or “Lexicon”
  – Consistent Terminology for Resources
  – Defined Start and Stop Activities (e.g. Design Reviews)
Collapsing steps reduced the number of activities tracked.
Process Simulation

• The PLEXUS tool provides the benefit of process simulations.
  – Explores trade-offs between Cost, Schedule, and Risk
  – Risk is reduced by iteration

• We have only recently fully populated our model data and look forward to exploring the potential of process simulations.
Some Lessons Learned

- It is difficult to improve processes you have not defined.
- Even the best experts struggle to describe their processes.
- COTS tools provide needed capability.
- Use Appropriate Level of Detail.
- Work at a consistent level of detail.
- Use Standard Lexicon.
- A process model provides means to capture expert knowledge.
- A process model is a training tool.
Other Plans

1. **Expanding the scope of our model; working with other organizations to:**
   - Capture their process steps
   - Define process dependencies within the domain of the other agency
   - Define inter-dependencies with other agencies

2. **Relating products to the high level DoD acquisition process**

3. **Building a “practice”**
   - Not cost effective to train everyone in use of the model
   - Establishing small group of experts that assist in planning of new ship design projects, process improvement, software evaluation, or training
   - Naval Surface Warfare Center, Carderock Division (NSWCCD) is the home for this practice and trains young naval engineers.

4. **Demonstrating effectiveness of model for new ship designs**

5. **Applying risk and simulation capabilities**
Summary

- Complex engineering projects benefit from process models providing:
  - A means for planning work
  - A way to evaluate alternative processes
  - ROI estimates for new software
  - Training of new employees.

- Design Structure Matrix methods can be used to:
  - Capture process definition in a facilitation setting
  - Provide insights into process complexity
  - Explore multi-domain relationships
  - Describe process activities and dependencies in a compact format

- Commercial off-the-shelf process modeling software is available.

- Using standard nomenclature is recommended.

- The time and effort in process modeling is worthwhile.
Thank you very much.
Warship Complexity

- Off the Grid
- Airports
- Mobile and survivable in any weather
- Nuclear Power Plant

4,000 to 5,000 live-aboard operators

Concept | Preliminary | Contract | Detailed Design & Construction
---------|-------------|----------|----------------------------------
10 to 15 year process
Complex Process Interactions

Many interactions at all levels.

Mission Systems Design Development

Aviation Systems

Weapons Systems

Combat Systems

H, M, & E Design Development

Hull Systems

Mechanical Systems

Electrical Systems
Process Database Methods

• Process order is important.
• Organizational structure is also important.
• Other factors to track:
  – Work breakdown structure
  – Geographic location
  – Software required
  – Resources
  – Schedule

• Need to track large amounts of data
• Prepared schema for process database

Planned to create a tool to model our process; Found COTS software that met our needs.
Challenges

- Organizational Resistance
- Individual Resistance
- Willingness and Ability to Support Process Modeling
- Lack of Current Process Definition
- Experts Not Articulate about Process Steps
- Complexity
- Imprecise or Ambiguous Language
- Investment
  - Software Costs
  - Indirect Labor Costs
  - Schedule Availability & Priority

Mitigation Strategy

- Management Briefings
- Management Priority
- Independent Group Facilitating Process Modeling
- Workshop Facilitation
- Workshop Facilitation Provides Lexicon and Encouragement
- Capable Modeling Tools
- Standard Definitions & Lexicon
- Briefing Key Managers to build Support and Line Up Funding for FY12 and Beyond
- Installing software on server to provide broader access.
Risk Trade-Offs

Increased Iteration Decreases Risk Metric